TITLE

ROBOTIC APPARATUS FOR PAINTING

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. provisional patent application serial no. 60/420,612 filed October 23, 2002, the U.S. provisional patent application serial no. 60/ 420,971 filed October 24, 2002, and the U.S. provisional patent application serial no. 60/ 423,636 filed November 4, 2002.

BACKGROUND OF THE INVENTION

The present invention relates generally to robotic painting systems and in particular to a robotic apparatus for applying electrically conductive paint to the external surfaces of automotive vehicle bodies.

Prior art paint booths are well known. A typical prior art paint booth, used to paint the exterior surfaces of vehicle bodies in both continuous conveyance and stop station systems, includes an enclosure housing a plurality of paint applicators. In one configuration, the applicators are mounted on an inverted U-shaped support structure that includes two vertical supports, one on either side of the path of travel of the bodies, connected at their tops by a horizontal support. This support structure is used to paint the top surfaces of the body and the horizontal beam can be fixed or can have an additional degree of freedom to move along the top of the vehicle body being painted. Another painting device is used in the same painting zone to paint the sides of the body and generally does not have the capability to move laterally along the length of the body. Disadvantages of this type of painting apparatus include lack of flexibility to provide optimized standoff distance between the body surface and the applicator along with inefficient use of the allotted painting cycle time. In the case of the top surface painting machine, the paint applicators are mounted on a common beam: therefore, the distance between each paint applicator and the surface to be painted varies with the contours of the vehicle body. In the case of the side painting machine, the paint applicators do not move transverse to the path of the vehicle body. They can only paint the portion of the body that is in front of the applicator leaving a good portion of the available cycle time unused.

A more recent alternative to the support structure has been floor-mounted robots disposed along the sides of the painting booth. The robots mount either spray guns or rotary applicators (bell machines) for directing atomized paint toward the vehicle body.

While rotary applicators have advantages over spray guns, there are some associated disadvantages. The prior art floor mounted robots, especially bell machines, are inherently very costly and limit visual access to the spray booth. The bell machines require more bells for the same throughput due to limited orientation capability. The additional bells use more paint per vehicle due to per bell paint waste during color changing. Prior art floor mounted robots also require significant booth modification when installed in existing paint booths, increasing installation time and cost, and require more booth length and width. The rail axis of floor mounted robots requires doors at both ends of the booth. The waist axis of the floor mounted robot requires an additional safety zone at the ends of the spray booth and the rail cabinets of the floor mounted robots encroach into the aisle space. Floor mounted robots also require frequent cleaning due to the down draft of paint overspray causing paint accumulation on the robot arm and base, which results in higher maintenance and cleaning costs.

The prior art bell zone machines also lack flexibility. Additional and more flexible robot zones are required because the prior art machines unable to reach substantially all paintable surfaces on one side of the body and, therefore, have limited backup capability for an inoperative painting machine. Additional robot zones are also used to provide backup capability for the less flexible prior art painting machine.

It is desirable, therefore, to provide a painting apparatus and a painting system that utilizes robots in an efficient and cost-effective manner that minimizes paint waste, occupies little space (length and width) in the paint booth and can be installed in existing paint booths without requiring significant booth modification. It is also desirable to provide a painting apparatus wherein one painting robot is able to reach substantially all paintable surfaces on one side of the article to provide backup capability in the case of an inoperative robot.

Due to the conductivity of the waterborne paint, it is necessary to electrically isolate the grounded bulk paint supply system from a charged local dispensing canister and spray application system. In the prior art, the bell applicator, canister, canister drive, electrostatic cascade, and docking interface were all integrated into a single unit mounted

on the robot wrist as shown in the U.S. Patent No. 5,293,911 and the U.S. Patent No. 5,367,944. Such an applicator had the following shortcomings:

1) The applicator is heavy, expensive, and subject to damage via collision with objects in the painting booth.

2) The applicator docking with a docking station must occur in a fixed booth position and therefore limits process flexibility.

3) The docking process takes cycle time as the robot must travel to and from the docked position. The canister filling can not start until the applicator reaches the docked position.

4) The docking hardware is expensive and unique to waterborne systems.

Another method to isolate the bulk paint supply system from the charged paint dispensing canister is to clean and dry the paint transfer line between the supply system and the canister. The cleaning and drying of the transfer line between the bulk supply system and the paint dispensing canister has not been successfully implemented in an automotive type painting system (rapid color changing on a continuous conveyance type system). There are several reasons why this type of system has not been used in the past. These shortcomings include:

1) The time to clean and dry the line and provide high voltage isolation exceeds the allotted dwell time between the vehicle bodies being painted.

2) The high voltage cannot be easily contained and thus the isolation system is compromised (arcing and pin holing). The electrostatic erosion can burn holes in the transfer line, the dispensing system, the supply line to the applicator, or the waste collection lines. The resultant down time would not be readily accepted for this type of application.

3) The amount of waste that is left in the paint transfer line is excessive when compared to other means of isolation.

4) The acceptable voltage limit does not provide high painting transfer efficiency as compared to other means of voltage isolation.

SUMMARY OF THE INVENTION

The present invention concerns an apparatus, method, and system for painting objects in a paint booth or similar enclosure.

The improvements rendered to overcome these shortcomings provide a cost effective solution to effectively utilize the environmental benefits of today's waterborne coatings.

The present invention concerns a painting apparatus including: an arm adapted for use with a painting robot, the arm having a housing formed of a non-conductive material; a color changer mounted on an exterior surface of one side of the housing, the color changer adapted to be connected to a paint supply; a paint canister mounted inside the housing; and a paint transfer line connecting the color changer to an interior of the paint canister for transferring paint from the color changer to the interior of the paint canister. The paint transfer line is formed of an electrically insulating material such as FEP material. The apparatus has a wrist attached to the arm, the wrist having a wrist housing formed of an electrically insulating material and the wrist being adapted to mount a paint applicator. A piston ram is mounted in the housing and is connected to the paint canister for controlling a flow of the paint into and out of the paint canister. The piston ram includes a piston releasably attached to a ram body by a ram locking key. The apparatus includes a canister quick disconnect for releasably attaching the paint canister to the piston ram wherein the canister quick disconnect includes convex locking means on the piston ram releasably engaged with concave locking means on the paint canister. The piston ram includes a ball screw and cooperating ball screw nut and including a drive motor connected to the ball screw for actuating the piston ram.

The painting apparatus according to the present invention also comprises: an arm adapted for use with a painting robot; a paint canister mounted inside the arm; a piston ram mounted inside the arm and having a piston movable inside the paint canister; and a canister quick disconnect releasably attaching the paint canister to the piston ram. A drive motor is connected to the piston ram for moving a piston in the paint canister wherein a torque generated by the drive motor represents a pressure being applied to the piston by paint in the paint canister.

The present invention further concerns a method of operating a robotic painting apparatus comprising the steps of: a) providing a color changer adapted to be connected to a paint supply; b) providing a paint canister connected to a paint applicator; c) connecting an electrically insulating paint transfer line between the color changer and an interior of the paint canister; d) transferring a quantity of paint from the color changer to

the interior of the paint canister; e) cleaning and drying an interior of the paint transfer line; f) applying high voltage to charge the quantity of paint; and g) dispensing the paint from the paint canister to the paint applicator. The method includes performing the step d) by transferring paint remaining in the paint transfer line to the paint canister prior to performing the step e). The method also includes starting the step f) before completing the step e). The method further includes sensing a pressure generated as the quantity of paint is being transferred during the step d) and utilizing the pressure sensing to optimize the paint transfer process as well as protecting the system from over pressurization in case of an equipment malfunction. The amount and flow rate of the paint transferred to the paint canister or to the paint applicator is controlled by the drive motor position or the drive motor velocity.

DESCRIPTION OF THE DRAWINGS

The above, as well as other advantages of the present invention, will become readily apparent to those skilled in the art from the following detailed description of a preferred embodiment when considered in the light of the accompanying drawings in which:

Fig. 1 is a perspective view of a modular elevated rail apparatus in accordance with the present invention;

Fig. 2 is fragmentary perspective view of an alternate embodiment of the elevated rail apparatus according to the present invention shown installed in a painting booth;

Fig. 3 is a fragmentary cross sectional view of a portion of the elevated rail apparatus of Fig. 1 installed in a painting booth in a first configuration;

Fig. 4 is a fragmentary cross sectional view similar to Fig. 3 showing the elevated rail apparatus installed in a painting booth in a second configuration;

Fig. 5 is a perspective view of one of the painting robots shown in Fig. 1;

Fig. 6 is a front elevation view of the elevated rail apparatus of Fig. 1 installed in a painting booth for painting a vehicle body;

Fig. 7 is an enlarged perspective view of the outer arm shown in Fig. 5 from the color changer side;

Fig. 8 is an enlarged fragmentary perspective view of the outer arm shown in Fig. 5 from the canister side in;

Fig. 9 is a perspective view of the canister and drive assembly shown in Fig. 8;

Fig. 10 is an enlarged exploded perspective view of the canister quick disconnect shown in Fig. 9; and

Fig. 11 is an enlarged exploded perspective view of the quick disconnect piston ram shown in Fig. 9;

DESCRIPTION OF THE PREFERRED EMBODIMENT

There is shown in Fig. 1 a modular elevated rail apparatus **10** for painting articles or objects in accordance with the present invention. The elevated rail apparatus **10** is adapted to be disposed in a paint booth as discussed below. The apparatus **10** includes a pair of frame rails **11** extending in a horizontal direction and spaced apart a predetermined distance on opposite sides of an axis **12** defining a path of travel for objects to be painted. Each end of each of the frame rails **11** is supported on an upper end of an associated one of a plurality of legs **13** adapted to engage a floor of the painting booth. Corresponding ends of the frame rails **11** can be connected by cross support members **14** that cooperate with the frame rails **11** and the legs **13** to form a modular, rigid supporting frame structure of the apparatus **10**. If required for support, additional ones of the legs **13** and the members **14** can be attached intermediate the ends of the frame rails **11**.

The frame rails **11** each have at least one mounting base **15** attached thereto. Three such bases **15** are shown on each of the rails **11**. Each of the mounting bases **15** is adapted to retain a painting device **16**. The preferred painting device **16** is a robotic four axis articulated arm terminated at a free end by a paint applicator **17**. The arm includes a shoulder axis, an elbow axis, a wrist rotating axis and a wrist tilting axis. Although a rotary bell atomizer is shown as the paint applicator **17**, any known device such as a spray gun could be used. The painting device **16** and the mounting base **15** move together parallel to the longitudinal axis **12** to provide a fifth axis of movement. The painting device **16** is provided with electrical power and fluids, such as paint, compressed air and solvent, through a flexible ribbon **18** connected between the painting device and the frame rail **11**. Preferably, the painting devices **16** are mounted in opposed pairs for simultaneously painting opposite surfaces of an object such an automobile body or the like (not shown) moved through the apparatus **10** along the axis **12**. If the shown

location of the axis **12** represents the top surfaces of the objects being painted, the frame rails **11**, the support members **14** and the mounting bases **15** may be advantageously spaced a predetermined vertical distance **19** above the horizontal plane containing the axis **12**.

The elevated rail apparatus **10** can easily be installed as a new painting booth is constructed, or as a retrofit to an existing paint booth without requiring significant modification to the existing paint booth. The frame rails **11**, the legs **13** and the support members **14** can be brought into a painting booth and assembled into the rigid frame structure. Although the elevated rail apparatus **10** is described in terms of a painting process, the paint applicator **17** can be any tool suitable for performing a process on an object moved along a path.

An alternate embodiment elevated rail apparatus **20** according to the present invention is shown in Fig. 2 installed in a painting booth **21**. The painting booth **21** includes a rear or exit wall **22**, a lower wall or floor **23**, a front or entrance wall **24**, a pair of side walls **25** and a top wall or roof **26**. The right side wall **25**, the front wall **24** and the top wall **26** are cut away to permit the interior of the booth **21** to be seen. The walls **22** through **26** are connected together to define an enclosed space in which the elevated rail apparatus **10** of Fig. 1 may be advantageously disposed. However, the alternate embodiment elevated rail apparatus **20** is adapted to be disposed in an upper portion of the paint booth **21** on the side walls **25**. The apparatus **20** includes the frame rail **11** extending along an interior surface of the left side wall **25**. The frame rail **11** can be attached to the side wall **25** by any suitable means. A second one of the frame rails **11** (not shown) is positioned on the opposite interior surface of the right side wall **25** such that the booth connects the frame rails **11** in a rigid frame structure. Movably attached to the frame rails **11** are the mounting bases **15** with the painting devices **16** and the painting applicators **17**.

There is shown in Fig. 3 a portion of the apparatus **10** at a side wall of the painting booth. The side wall is split with an upper portion **25a** above the frame rail **11** and a lower portion **25b** below. The upper portion **25a** abuts an upper surface **11a** of the frame rail **11** near an outer side surface **11b**. The lower portion **25b** abuts a lower surface **11c** of the frame rail **11** near an inner side surface **11b** to which the cross support member **14** is attached. Thus, the frame rail **11** forms a part of the side wall separating

an interior space **27** of the painting booth from an aisle **28** outside the booth. The frame rails **11** are made of tubular stock and are preferably rectangular in cross section having a hollow interior **11e**. Alternatively, the frame rails **11** are formed from any shape of tubular stock including, but not limited to, circular stock. A coupling conduit **29** is attached to the surface **11b** for routing electrical and fluid lines from the aisle **28** into the interior **11e** of the frame rail **11**. The cross support members **14** also are tubular for routing electrical and fluid lines. The frame rails **11** and the cross supports **14** can be sealed, purged and pressurized to function in the painting booth environment.

There is shown in Fig. 4 a portion of the apparatus **10** at the side wall **25** of the painting booth wherein the entire apparatus **10** is located in the interior **27** of the booth. A coupling conduit **30** is attached to the surface **11b** for routing electrical and fluid lines into the interior **11e** of the frame rail **11**. The coupling conduit **30** extends through the side wall **25** into the aisle **28**.

Elevating the frame rails **11** above the path of the upper surfaces of the objects being painted allows a simple means for connecting the cross support members **14** between the opposing frame rails providing a path for any supply lines. Thus, the electrical power and fluid sources can be located in the aisle **28** adjacent the exterior of the left side wall **25**, for example, to supply the painting devices **16** on both sides of the booth. Also, it is advantageously less costly than adding support steel to the paint booth to support the cantilever loads of traditional prior art floor mounted robot rails.

In addition, elevating the frame rails **11** places many of the typical maintenance components such as linear axis drive components and cable and hose carriers (not shown) out of the area where the paint overspray would typically accumulate on equipment in a prior art down draft spray booth. These components do not need to be protected against the overspray as diligently as a prior art floor mounted rail. This advantageously lowers the cost for protective covers and seals (not shown) while lowering the ongoing maintenance cost over the life of the robots **16**. Elevating the frame rails **11** also permits unobstructed viewing into the paint booth **21**, through windows **31** (see Fig. 2) provided in the side wall **25**, which is a benefit for system operators. The elevated rail apparatus **10** and **20** also allows access doors (not shown) to be placed in the side walls **25** when they would typically be located at the rear wall **22**

and the front wall **24** of the booth **21**. This again reduces the overall length of the booth **21**.

Furthermore, elevating the frame rails **11** above the object, such as a vehicle, vehicle to be painted allows the booth **21** to be made narrower than required for a traditional five to seven axis robot and does not require installation of components in the aisle **28** that are typically found in prior art floor-mounted installations. The elevated frame rail **11** and the robots **16** also advantageously allow the arm of each of the robots, discussed in more detail below, to reach under itself and paint the side of the vehicle because the robot base is not trapped between the side wall **25** and the vehicle.

As shown in Figs. 1 and 2, a plurality of the articulated arm robots **16** is attached to the elevated frame rails **11** at various mounting bases **15** that move along the rails and allow the applicators **17** to follow an object to be painted, such as a vehicle body (not shown), as it moves through the paint booth **21**. The applicators **17** are preferably a circular spray pattern bell applicator. By installing multiple articulated arm robots **16** on the common frame rails **11**, the vehicle can be processed with each applicator **17** spraying for a higher percentage of time, and requiring fewer of the robots **16** and corresponding applicators **17** as compared to floor mounted systems.

With a simplified robot **16**, the design of the structural elements of the elevated rail apparatus **10** and **20** (the frame rail **11**, the legs **13** and the cross supports members **14**) are fit within the narrow width space limitations of a standard bell zone paint booth **21**. Furthermore, utilizing the elevated rail apparatus **10** in conjunction with the higher flexibility of a multi-axis manipulator, discussed in more detail below, yields higher application efficiencies, and thereby reduces the length overall length of a traditional bell zone paint booth **21**.

As shown in Fig. 5, the preferred painting device **16** is a four axis articulated arm robot terminated at a free end of the arm by the paint applicator **17** shown as a rotary bell applicator. The robot **16** includes a first or inner arm portion **32** mounted at a first end to a robot base **33** for rotation about a shoulder axis **34**. A second or outer arm portion **35** is mounted at a first end to a second end of the inner arm **32** for rotation about an elbow axis **36**. A wrist **37** attaches the paint applicator **17** to a second end of the outer arm **35** and has a rotating axis **38** and a tilting axis **39**. The wrist **37** rotates the applicator **17** about the axis **38** which is generally parallel to a longitudinal axis of the outer arm **35**

and rotates the applicator **17** about the axis **39** to tilt the applicator relative to the axis **38**. Thus, the robot **16** provides four axes of motion relative to the base **33** for movement of the arm portions **32** and **35**, the wrist **37** and the applicator **17** in vertical planes. A fifth axis of motion is a rail axis **40** provided through the attachment of the robot base **33** to the mounting base **15** (Fig. 1) for reciprocating movement of the robot **16** along the horizontal longitudinal axis of the associated frame rail **11** (Fig. 1).

Preferably, the structural components of the outer arm portion **35** and the wrist **37** are formed from a non-conductive material having suitable structural strength and impervious to the corrosive properties of solvents used in the painting environments, such as Lauramid A material. "Lauramid" is a registered trademark of Albert Handtmann ELTEKA Verwaltungs-GmbH of Biberach, Germany. The Lauramid A material is a castable polyamide Nylon 12G material that also provides for electrostatic isolation, cleanliness, cleaning capability, and weight advantages. Grounding of internal gearing (not shown) in the wrist **37** and other conductive components is not necessary for use in the paint booth **21** because they are suitably insulated. Non-grounded components are advantageously less likely to attract paint overspray resulting in a cleaner robot **16** requiring less maintenance and having better transfer efficiency of the paint to the vehicle, all resulting in less operating cost. The conductive components could also be charged at a lower or the same potential as the spray applicator.

A plurality of paint lines **41** is routed along the side of the inner arm **32** and the lines connect to a color changer **42** mounted in the outer arm **35**. The outer arm **35** houses a paint canister (not shown) for receiving a supply of paint through a selected one of the lines **41** and dispensing the paint to the applicator **17**. Also housed within the outer arm **35** is a high voltage cascade (not shown) for electrostatically charging the paint for application to the object being painted.

Fig. 6 shows the elevated rail apparatus **10** installed in the interior **27** of the painting booth **21** for painting a vehicle body **43**. The base **33** and the shoulder axis **34** of each of the robots **16** are located above the horizontal plane of the axis **12** of movement of an upper surface **44** of the vehicle body **43** which maximizes the capability of the robots. A one of the robots **16** dedicated to painting the top **44** of the vehicle body **43** can advantageously paint a side **45** of the vehicle body if necessary in a degrade mode, such as if a one of the robots **16** dedicated to painting the side fails, because of the

extension capabilities that the translation axes **34** and **36** provide. In addition, the elevated frame rails **11** and cross support members **14** allow for the placement of a process control enclosure **46** (Figs. 5 and 6), which includes pneumatic valves and bell control components (not shown), below the robot base **33** and in the paint booth **21**, in an easily accessible type X purge enclosure.

The robot **16** being attached to the movable mounting base **15** on the elevated frame rail **11** allows the applicator **17** to follow the vehicle body **43** as it moves through the booth **21**. By utilizing multiple opposed robots **16** on opposed frame rails **11**, and by using a line tracking motion capability, the vehicle body **43** can be painted with each applicator **17** spraying for a high percentage of the available cycle time. For example, the robots **16** adjacent to the exit wall **22** (Fig. 2) can be spraying a portion of one vehicle body while the robots **16** adjacent to the entrance wall **24** can be spraying a portion of another vehicle body.

The robot primary axes **34** and **36** advantageously operate the robot arm portions **32** and **35** in a vertically extending planar space with respect to the axis **12**. Opposed robots **16** are provided for symmetric painting of objects such as the vehicle body **43**. Preferably control lines (not shown) are run through the cross support members **14** in order for a single controller (not shown) to control a pair of the opposed robots **16** for painting the opposite sides of the vehicle body **43**.

The geometry of the robot **16** and the mounting base **15** allows one painting robot to reach substantially all paintable surfaces on the top **44** and one side **45** of the vehicle body **43** in a degraded mode of operation. The elevated rail apparatus **10** or **20** advantageously provides for the use of multiple robots **16** on the same frame rail **11** having the capability to paint various size vehicle bodies **43** within the paint booth **21**. The geometry of the robot **16** and the elevated mounting location also eliminates human safety issues associated with placing traditional prior art robots in proximity of manual spray zones. Because the robot **16** is a planar device with respect the longitudinal axis of the frame rail **11** and does not have a waist axis as in the prior art floor mounted painting robots, the robot **16** does not have the capability to extend the applicator **17** beyond the ends of the spray zone. Furthermore, the geometry of the robot **16** and the elevated mounting location allows the robot to extend underneath the frame rail **11** into a protected enclosure (not shown) so that the robot can be serviced while the remaining

robots **16** in the paint booth **21** continue painting. The protected enclosure has provisions for use of dynamic limiting devices to ensure operator safety.

The contents of the U.S. Provisional Patent Application Serial No. 60/423,636, filed November 4, 2002, entitled "Robotic Apparatus for Waterborne Painting", are incorporated herein by reference.

The outer arm **35** of the robotic painting device **16** of Fig. 5 is shown from the side of the color changer **42** in Fig. 7 and from the side of an internal paint canister **47** in Fig. 8. The outer arm **35** according to the present invention incorporates some of the features that were present in the traditional waterborne applicator and integrates them into a robotic paint application device whereby the arm and wrist components are constructed of a non-conductive material. A housing or shell **35a** of the robot outer arm **35** and a housing or shell **37a** of the wrist **37** are constructed of a suitable non-conductive material such as Lauramid A Nylon 12G. The color changer **42** having a plurality of electrically grounded color valves **42a** is mounted on an exterior side surface of the housing **35a** as best seen in Fig. 7. On the opposite side of the outer arm **35**, there is mounted the electrically charged paint canister **47** inside the wall of the housing **35a** thereby separated from the grounded color valves **42a** on the other side. This configuration allows the use of the same color valves **42a** and the same applicator **17** as used in a solvent paint system, thereby resulting in both lower cost and common hardware platforms. In addition to the cost savings, the described hardware arrangement also minimizes the weight of the hardware to be mounted on the robot wrist **37** which allows the use of a lower cost robotic manipulator to perform the painting function. Another benefit of integrating the waterborne hardware internal to the robot arm **35** is that it removes the hardware from "harms way" and from potential collisions that are frequent with hardware that is mounted on a robot wrist.

A key aspect of the present invention is the means by which the isolation of the paint canister **47** is achieved. Often, in prior art systems, a physical disconnection (or air gap) provided isolation between the paint canister and the paint supply. The electrostatics would be discharged and the applicator would physically connect to the docking station to receive the appropriate color and amount of paint. In the painting apparatus 16 according to the present invention, no docking is required and the electrostatic isolation is achieved through a minimal length of FEP (fluorinated ethylene

propylene) line that is cleaned, dried, and pressurized after the canister **47** is filled and prior to the electrostatic charge being turned on. As shown in Fig. 7, a paint transfer and isolation line **48**, formed of FEP material, is connected between an outlet of the color changer **42** and a canister manifold **49** in fluid communication with an interior of the canister **47**.

There is shown in Fig. 9 the canister **47** and an associated drive system. A quick disconnect piston ram **50** is retained in a drive bracket **51** mounted in the housing **35a** (Fig. 8). A drive motor **52** provides rotational power to a reducer **53** that is connected to the piston ram **50** through a coupling **54**. The piston ram **50** is a ball screw type drive that is utilized to dispense paint to the applicator **17** during a vehicle painting operation. The mechanism **50** features a ram attached to a piston (not shown) movable in a cylinder (not shown) formed inside the canister **47**, which allows the piston to be driven all the way to the bottom of the cylinder thereby minimizing paint waste and canister cleaning effort. This configuration, allows the canister drive motor **52** and the reducer **53** to be positioned in an elbow **55**, connecting the outer arm **35** to the inner arm **32**, thereby locating the motor **52** a considerable distance from the electrostatics (not shown) associated with the canister **47**. After a painting operation, the electrostatics are turned off and the dispensing canister **47** is isolated from the grounded paint supply lines at the color changer **42** by utilizing the insulating properties of the material (Lauramid A) from which the outer arm housing **35a** is formed. The dispensing canister **47** is mounted on the opposing side of the outer arm **35** from the color changer **42** and is fully surrounded by and enclosed in the insulating material of the housing **35a**.

When cleaning of the interior of the canister **47** is required, the attached piston/ram **50** is backed off the cylinder bottom to effectively clean the area between the piston face and the bottom of the canister. The attached ram allows the piston to be cycled (in/out) during the application of the solvent and air mixture. The cleaning of the canister **47** with a solvent and air mixture occurs at the same time that the paint line from the canister to applicator (not shown) is backflushed out an in-arm dump line. The solvent and air mixture can be created by cycling the solvent inlet and air inlet valves in opposing cycles or by use of a solvent and air mixing valve whereby the solvent and air valves are actuated at the same time and a volumetric flow control device is used to have a proper ratio of solvent and air for effective cleaning. After canister cleaning, the

system is ready to be filled with a new color of paint. A benefit of this system is that the cleaning process can begin while the manipulator (robot) is on route to the cleaning or "home" position.

To reduce repair time, the in-arm canister **47** must be easily removed for routine service and maintenance. The painting device **16** according to the present invention incorporates features that allow for removal of the canister **47** and the canister manifold **49** in four easy steps. The canister **47** is attached to the drive bracket **51** by a canister quick disconnect **56**. Firstly, the canister manifold **49** is disconnected from the arm housing **35a** by removing a plurality of fasteners **57** (see Figs 8 and 9). Secondly, the canister quick disconnect **56** is rotated until loose. This permits sliding movement of the disconnect **56** towards the canister manifold **49**. Thirdly, rotate a ram locking key (described below) to an open position. Fourthly, remove the canister manifold **49** and the canister **47** through a window **58** (Fig. 8) formed in the arm housing **35a**.

The canister quick disconnect **56** is shown in more detail in Fig. 10. The drive bracket **51** has a reduced diameter end **59** with a plurality of convex locking means **60** formed at spaced locations on an annular surface thereof. A spring washer **61** is retained between facing surfaces on the end **59** and a canister flange retainer **62** attached to an end of the canister **47** (not shown). A quick disconnect retainer **63** is slidably received on the canister **47** and is retained by the canister flange retainer **62**. A plurality of concave locking means **64** are formed on an interior surface of the retainer **63** and cooperate with corresponding ones of the convex locking means **60**. To assembly, the flange retainer **62** of the canister **47** is moved into engagement with the end **59** of the drive bracket **51** with the spring gasket **61** therebetween. The retainer **63** is moved toward the drive bracket **51** with the concave locking means **64** aligned in the spaces between the convex locking means. Then the retainer **63** is rotated in a counterclockwise direction to engage associated ones of the concave locking means **64** with the convex locking means **60**. To release the canister **47** from the drive bracket **51**, the assembly process is reversed.

The quick disconnect piston ram **50** is shown in more detail in Fig. 11. At one end is the coupling **54** including a ball screw **65** and a cooperating ball screw nut **66**. As the ball screw **65** is rotated by the drive motor **52** (Fig. 9) through the reducer **53** (Fig. 9), the ball nut screw **66** is moved along a longitudinal axis to either extend or retract a piston **67** attached at an opposite end of the piston ram **50**. The piston **67** is received in

the cylinder (not shown) formed in the canister **47** (not shown). The piston **67** is releasably retained on the piston ram **50** by a ram locking key **68**. The key **68** is generally C-shaped and is sized to slide radially into a semi-circular slot **69** formed adjacent an end of a ram body **70**. The slot **69** opens to a central bore **71** extending from the end surface of the body **70**. The piston **67** has a rod **72** extending longitudinally therefrom that is received into the bore **71**. The rod **72** has an annular groove **73** formed therein for receiving the key **68** to releasably attach the piston **67** to the ram body **70**. The key **68** can snap into the groove **73** or use any well-known detent mechanism to engage in the slot **69**.

The various modes of operation of the painting device 16 are as follows with reference to Figs. 5 and 7-11:

A. Fill Through Restrictor and Torque Sensing – With the piston **67** slightly pulled away from the cylinder bottom and an applicator trigger valve open, the paint flows from the selected one of the color valves **42a** through the isolation line **48** and into the canister **47**. As the initial volume of the canister is filled through the trigger passage, air is pushed out of the system until the paint reaches a restriction in the trigger fill passage. At this time there is a sudden rise in pressure in the system due to the viscosity difference between the paint and the air being displaced by the paint. The pressure increase will cause the torque applied by the drive motor **52** to the ball screw **65** to increase which can be sensed and used to provide automatic adjustment of the trigger fill time or as a diagnostic to allow the user to adjust a timed value. The canister **47** and canister manifold **49** are now "primed" (filled through the restrictor and trigger passage) and the system is ready for a "fast fill" mode of operation.

B. Fast Fill with the Attached Piston and Ram - The attached piston and ram combination **50** allows the system to be utilized in several ways to minimize the canister fill time. A first way is to match the paint fill rate. If the paint fill rate into the canister **47** is known or can be automatically measured, the rate at which the canister piston mechanism **50** is retracted can be adjusted to minimize the pressure drop of the incoming paint and therefore decrease the fill time. The fill rate can be sensed by measuring either the servo error (positive or negative) or the motor torque applied to the canister piston mechanism. A second way is to set the fill rate below capability. The piston ram mechanism **50** can be retracted at a velocity that is known to be slightly below the system

fill rate capability. A third way is "syringing" of the paint with vacuum assist. The fill time can be decreased by pulling the attached piston ram **50** back at a rate greater than the fill rate capability of the bulk supply system. For example, the attached piston ram **50** can be quickly pulled back to the fill target position and held until the paint fill catches up. This will create a vacuum internal to the canister **47** and will further increase the fill rate of the paint.

C. Torque Sensing at the Fill Target - When the fill target is reached, the fluid pressure in the canister **47** will begin to increase. This increase in pressure can be measured via the torque that the drive motor **52** is applying to the ball screw **65**. When the torque increase is detected, the canister inlet valve can be closed. This feature can be used as a diagnostic tool to adjust the fill time or as an automatic means to adjust the fill sequence as described above. Moreover, the piston movement direction can also be reversed toward the dispensing direction instead of the fill direction to ensure that the system is filled correctly and devoid of entrapped air. The inlet and outlet valves are closed while the piston moves forward in the dispensing direction as the entrapped air is compressible, whereby a fluid filled system devoid of entrapped air would quickly build pressure. This pressure can be sensed by the dispensing canister drive system.

D. Utilization of Air or Solvent to Push to Minimize Paint Waste - Due to the high cost of the paint product, it is very important to minimize all sources of color change paint waste. Because of this, the capability to utilize the volume of paint internal to the paint color valves **42a** and the isolation line **48** is provided. The volume of paint from the color valves **42a**, through the isolation line **48**, to the canister **47** can be referred to as "V2". If we assume that the Fast Fill operation as described above was to a volume "V1", the Total Fill Target = V1 + V2. After the fast fill to the volume "V1" has occurred, the piston **67** is stopped, the paint supply valve is closed, the air or solvent supply valve is opened and the piston **67** is then retracted at a rate such that a great portion of the paint in the line **48** is pushed or pulled into the dispensing canister **47**. When the Total Fill Target volume is reached, the canister inlet valve is closed and the air supply valve is shut off. The canister pressure will increase which can be detected by the increasing motor torque, which is used to confirm that the system is properly filled. The fill process is now completed. In addition to the mechanical hardware to achieve

such an air push, software controls (located in the process control enclosure **46** of Fig. 6) are required to successfully accomplish the air push operation.

E. Utilization of Paint Pig to Minimize Paint Waste - The system is also capable of utilizing a non-connected piston (paint pig, not shown) which is injected into the transfer line **48** at the beginning of the color changer (furthermost point in the transfer line away from the isolation/dispensing canister **47**) and is used to fully expel the paint into the isolation canister. The line can be cleaned and dried behind the pig such that isolation means are provided. The pig is then pushed back after the painting cycle and the process is repeated.

F. Cleaning of the Isolation and Dump Lines - After the filling of the canister **47** and the air push, any remaining paint in the isolation line **48** and the dump line must be cleaned with the solvent and air, or a solvent and air mixture, and then dried. After the isolation line and the dump line are cleaned, the high voltage can be turned on to charge the paint supply. While the high voltage is turned on, a flow of air can be maintained in the isolation line **48** or the isolation line can be pressurized with dry air. The in-arm dump line terminates at some point within the application vicinity and the downstream end of the line is electrostatically isolated from ground potential. As a result, no unintended physical disconnect to ground can occur.

G. High Voltage on with Current Limiting Function – The high voltage can be applied as the line drying process takes place. The voltage is limited by a maximum current setting which is programmed into the high voltage control unit. As the transfer line **48** is dried, the high voltage increases to the required setting for painting. This process can be accomplished as the painting device (robot) **16** moves to the starting position for painting, thereby reducing the overall cycle time.

The isolation system according to the present invention, as described above, can be used for both rotary atomizers and automatic spray guns.

In accordance with the provisions of the patent statutes, the present invention has been described in what is considered to represent its preferred embodiment. However, it should be noted that the invention can be practiced otherwise than as specifically illustrated and described without departing from its spirit or scope.